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The Effect of Using Various Types of Clay on the Mechanical Properties of Plastic Concrete

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ABSTRACT

Plastic concrete, as a construction material with high workability and low permeability, is widely used in the construction of hydraulic structures. Clay, as one of the main components of plastic concrete, plays an important role in improving its properties. However, plastic concrete faces challenges such as longer curing time and low strength. Moreover, permeability in plastic concrete is one of the key issues that needs to be studied. Therefore, this study investigates the mechanical properties and permeability of plastic concrete made with two types of clay: clay from the Baghmisheh region of Tabriz and the same clay that has been processed for use in ceramic clay. Clay was used to replace cement at three different percentages: 10%, 20%, and 30% and a sample without clay was prepared for comparison. The prepared samples were evaluated through a series of tests, including compressive, tensile, flexural strength, water absorption, and permeability. The results indicate that Baghmisheh clay, due to its higher plasticity, had negative impact on the mechanical properties compared to Ceramic clay. By increasing in the content of both types of clay, compressive, tensile, and flexural strengths were significantly reduced. This reduction is attributed to the partial replacement of cement with clay, which increased porosity of the concrete, and decreased bonding between its particles. Water absorption and permeability coefficient of the concrete increased considerably with higher clay content, particularly in mixes containing Baghmisheh clay. Overall, concrete containing Baghmisheh clay exhibited lower strength and was more vulnerable to water and chemical penetration.

Keywords: plastic concrete, plasticity, clay, permeability, mechanical properties,

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1. INTRODUCTION

Dams are typically made in high permeability areas. Therefore, controlling groundwater and their leakage is one of the most important issues in the stability of dams, tunnels and many concrete structures related to soil. Due to the accumulation of large amounts of water behind the dam, one of the ways to reduce and control the water

leakage from the back of the dam is to use the cut-off walls. The cut-off walls must have high plasticity and low permeability [1].

For this reason, plastic concrete could be one of the solutions. Plastic concrete has a higher formability, but lower compressive strength and permeability, resulting from the usage of clay slurry in the concrete

mix design [2]. Plastic concrete consists of aggregate, cement, water, and clay mixed at a high water cement ratio to produce a ductile material than conventional structural concrete [2]. Plastic concrete shows great promise for satisfying the strength, stiffness, and permeability requirements for remedial cut-off wall construction [3]. In general, using higher water to cement ratio in the mixing design increases plasticity and reduces permeability. However, this case cause aggregates to be separated from cement. For this reason, at these ratios, we use clay in mix designs. Clay acts as a stabilizing agent in plastic concrete and prevents aggregate from having separated from cement and it creates a homogeneous mixture. The properties of clay include plasticity, ion succession and ionic contraction. While using in concrete, clay acts as an ion exchange. This makes the mixture homogeneous and stable, which in addition to preventing the separation of aggregate from the cement, it results in the uniformity of the molecular arrangement of the mixture and increases the plasticity and decreases permeability [4,5]. Clay has high water absorption and swells about 300% after combining with water. These properties make saturated clay workable in plastic concrete in order to eliminate the damaging effects of high water absorption of dry bentonite [6].

Amlashi et al. (2019) investigated the soft computing based formulations for slump, compressive strength, and elastic modulus of bentonite plastic concrete (BPC). Parametric study indicated that increasing clay contents leads to the reduction of slump, compressive strength, and elastic modulus due to the adsorption of water by clay particles. Moreover, at constant amounts of clay, increasing the ratio of gravel to sand improves the strength parameters of BPC. While increasing the amount of water increases the slump of BPC, the slope of this ascending trend turn into zero at water contents greater than 0.34 Kg/m³. There is an inverse correlation between water content and strength parameters of BPC. At constant amounts of water, increasing the clay to cement ratio leads to an increase in slump and reduces compressive strength and elastic modulus [7].

Shepherd et al. (2020) reviewed about plastic concrete for cut-off walls. The review presented here confirms that Plastic Concrete may be considered to be a low-strength, low-stiffness impervious concrete with high deformation capacity under load, but also

supports the need for further investigations into the mechanical and hydraulic material properties [8].

Taher Shamsi et al. (2009) investigated the effect of two types of clay minerals on the compressive strength of plastic concrete made from them. The results of this research indicated that if the compressive strength criterion of the samples is used to evaluate the extent of the effect of the clay type on the mechanical properties of plastic concrete, the addition of bentonite clay has more favorable consequences than kaolinite clay in plastic concrete [9].

Fadaie et al. (2019) investigated the effect of dry and saturated bentonite on plastic concrete. In order to saturate bentonite clay, plastic concretes must be mixed with water at least 24 hours before usage and then they must be blended by special blades. This process costs huge time and money. Therefore, in this research, dry bentonite has been added to the mixer with particular method. It can be seen saving time and money and the properties of plastic concrete such as compressive strength, tensile strength, slump and permeability will not be slightly changed [1].

Memon et al. (2012) examined Pakistani bentonite as a part of Portland cement. They examined the use of bentonite as pozzolan is an environmental friendly option. Technically and financially, bentonite has lots of potentials to be used as pozzolan in the concrete construction industry. They also indicated that the workability, density and water absorption decrease by replacing bentonite with cement

Kaci et al. (2011) investigated the influence of bentonite clay on the rheological behavior of fresh mortars, and more particularly on the ability of the material to recover yield stress after being sheared at high rates. By determining the flow curves at controlled stresses, the mortars initially showed a rheopectic behavior. This rheopectic aspect was attributed to the diminution of the lubricating effects of the fine particles suspensions due to their shear-thinning property. It was found that bentonite increases both the level of yield stress recovered after shear and the kinetics of the microstructure rebuild up. Adding more bentonite can enhance the shear induced thickening effect [10].

Abbaslou et al. (2014) investigated effect of sepiolite clay mineral on the compressive strength of plastic concrete. The research aimed to evaluate sepiolite clay as a replacement for bentonite and investigate its workability. Compressive strength results showed that replacing bentonite with sepiolite, despite

having plasticity, leads to higher optimal strength. Laboratory findings regarding the impact of the mineralogical structure of different clays on the strength properties of plastic concrete, which are important for dam construction applications, indicate a significant difference between the tested samples [11].

In this article, plastic concrete samples were made with two types of clays: clay from the Baghmisheh region of Tabriz and clay from the Baghmisheh

region that has been processed for use in ceramic clay. For this purpose, the clay soils replaced the Portland cement in three percentages of 10, 20, and 30, and were cured for 7 and 28 days. Compressive strength, tensile strength and flexural strength tests for mechanical properties, water absorption and permeability tests in terms of durability were conducted on the plastic concrete samples. The results were then compared.

2. MATERIALS AND METHODS

2.1. Cement

The cement used in this research is Portland Cement Type 2 of Soufian Cement Plant (East Azerbaijan),

the chemical and physical requirements are shown in [Table 1](#) and [2](#).

Table 1. Chemical Analysis of Soufian Cement

Component	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃ ⁻²	Na ₂ O	K ₂ O	I.R.	L.O.I
Percent (%)	21.70	5.22	3.74	64.44	2.22	2.00	0.22	0.58	0.62	1.36

Table 2. Physical Analysis of Soufian Cement

Fineness (Blaine) (cm ² /g)	Residue on 90 μ Sieve (%)	Autoclave Expansion (%)	Initial Setting Time (min)	Final Setting Time (min)	Density (Kg/m ³)	Compressive Strength (Kg/cm ²)			
						2 days	3 days	7 days	28 days
3230	3.86	0.18	115	185	3160	172	240	345	465

2.2. Clay

Based on the project objectives and research methodology, the effectiveness of two types of clay soil in plastic concrete was investigated. Both types of clay have been extracted from the Baghmisheh region of Tabriz. However, clay type A has undergone processing for use in ceramic clay, while type B is the raw, unprocessed clay as extracted. Clay is a fundamental raw material in the production of traditional and decorative tiles, requiring specific properties such as suitable plasticity, high adhesiveness, and resistance to cracking. Ceramic clay is extracted from natural deposits and undergoes processing to remove impurities and enhance its usability.

Initially, coarse particles and organic materials are separated through screening and, if necessary, sedimentation. The clay is then dried and may be ground to achieve a finer texture. Additives such as grog (fired and ground clay) or silica may be incorporated to improve its technical properties. Finally, the clay is kneaded and homogenized to produce a material ready for tile production [12]. The Baghmisheh region of Tabriz is one of the sources of ceramic clay in Iran, where the extracted clay, once processed, is widely used in the making of traditional tiles. [Table 3](#) shows the LL, PL, PI and special gravity (GS) of clays.

Table 3. Physical Analysis of Clays

Clay Type	LL	PL	PI	GS (Kg/m ³)
Ceramic clay	29%	22%	7%	2581
Baghmisheh region Clay	34.7%	17.6%	17%	2691

2.3. Aggregate

The aggregate used in this research was fine and coarse aggregate of the Marand Qara Qoum Mine

and their particle size distribution charts are shown in [Figures 1](#) and [2](#).

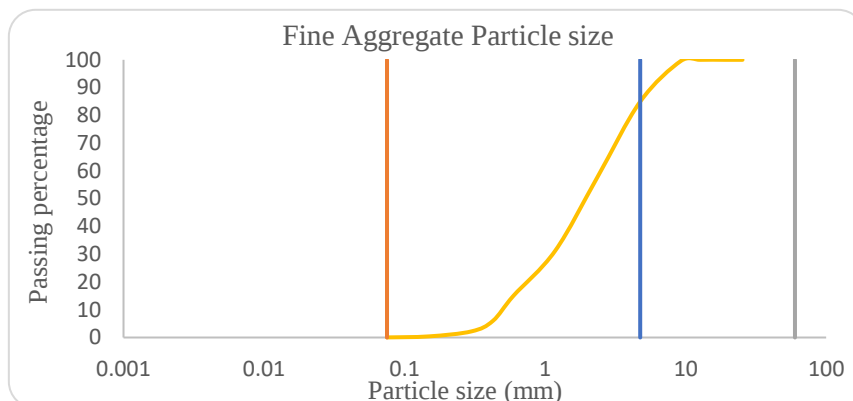


Figure 1. Fine Aggregate Particle size

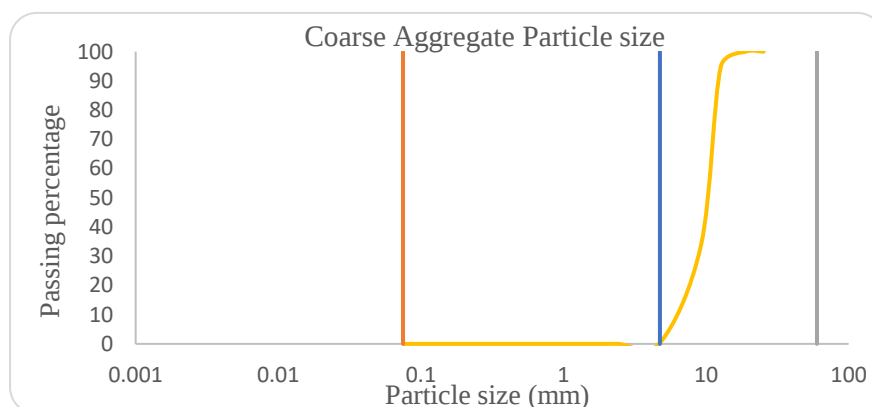


Figure 2. Coarse Aggregate Particle size

2.4. Water to Cement Ratio

One of the characteristics of plastic concrete is the high ratio of water to cement. This high ratio added to clay increase deformation and decrease

permeability and compressive strength. In this study, the water to cement ratio was considered to be 0.75.

2.5. Mix Design

Given that the aim of this research is to investigate the effect of adding two types of clay in different percentages, the volumetric method was used for the mix design of the prepared samples. The plastic

concrete samples were grouped into two samples that include: A) Ceramic clay and B) Baghmesheh region clay. [Table 4](#) shows the weight of the materials used in the mix design.

Table 4. Mix Design

Sample Name	Cement (Kg/m ³)	Clay (Kg/m ³)	Water (Kg/m ³)	W/C	Coarse Aggregate (Kg/m ³)	Fine Aggregate (Kg/m ³)
CL0 (Control)	297.0	0	146.2	0.45	606.4	1438.1
CLA10	267.3	29.7	234.8	0.75	535.1	1269.0
CLA20	237.6	59.4	234.8	0.75	533.4	1265.1
CLA30	207.9	89.1	234.8	0.75	531.8	1261.2
CLB10	267.3	29.7	234.9	0.75	535.4	1269.9
CLB20	237.6	59.4	234.9	0.75	534.2	1266.8
CLB30	207.9	89.1	234.9	0.75	532.9	1263.8

2.6. CONSTRUCTION METHOD AND EXPERIMENTS

2.6.1. Plastic Concrete with Clay

For the mix design of this research, the required clay was initially saturated in a portion of the mixing water for 24 hours. In the next step, coarse aggregate and one-third of the mixing water were added to the mixer, and mixing continued for 5 minutes. Then, cement and another one-third of the mixing water were added to the mixer, and the mixing operation was continued again for 5 minutes. In the following

step, fine aggregate along with the remaining one-third of the mixing water were added to the mixer, and the mixing operation continued for 5 minutes. Finally, the clay was added to the mixer, and the mixing operation continued for 10 minutes. After 10 minutes, the samples were molded and kept at $\pm 22^{\circ}\text{C}$ temperature for 24 hours.

2.6.2. Curing of Samples

Curing of specimens was done according to ASTM C192 (13) in the cure box. The water temperature in

cure box was 20°C to 23°C . The samples were completely soaked in water.

2.7. Compressive Strength Test

Compressive strength is one of the most important properties of hardened concrete for classification in international standards. This test is performed according to ASTM C39 (14) on $10 \times 10 \times 10$ cm cubic samples as shown in [Figure 3](#). The specimens were

broken at 7 and 28 days. To obtain the compressive strength of the specimens, the maximum applied force is divided by the cross-sectional area of the sample. The Results were showed in Table 5.

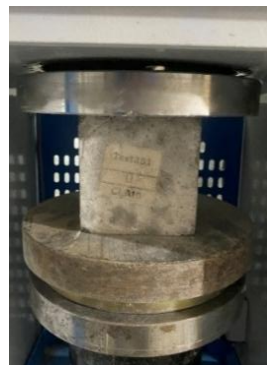


Figure 3. Compressive Strength Test on Samples

2.8. Tensile Strength Test

This test, known as the splitting tensile strength of concrete or the Brazilian test and is performed according to ASTM C496 [15]. For the tensile strength test in this research, three cylindrical specimen with dimensions of 10×20 cm were used for each sample as shown in [Figure 4](#).

According to ASTM C496, the tensile strength of the specimen is calculated using [Eqs. \(1\)](#):

$$T = \frac{2P}{\pi LD} \quad (1)$$

In which T is the tensile strength of the specimen in MPa, P is the compressive force in N, L is the length of the specimen in mm and D is the diameter of the cylindrical specimen in mm.



Figure 4. Tensile Strength Test on Samples

2.9. Flexural Strength Test

For the flexural strength test in this research, three prismatic beams with dimensions of 10x10x45 cm were used for each sample as shown in [Figure 5](#). This test is performed according to ASTM C78[16]. Considering the static stability of the beam, pure bending exists in the middle third of the beam. If a newly formed crack on the tension surface is within the middle third of the span length, we use [Eqs. \(2\)](#):

$$R = \frac{PL}{bd^2} \quad (2)$$

In which R is the flexural strength of the specimen in MPa, P is the compressive force in N, L is the span length of the specimen, which is 390 mm, b is the width of the beam cross-section which is 100 mm and d is the height (depth) of the beam cross-section which is 100 mm.

If the crack that occurs on the tension surface is outside the middle third of the span length but not more than 5 percent of the span length, the modulus of rupture is obtained from [Eqs. \(3\)](#):

$$R = \frac{3PL}{2bd^2} \quad (3)$$

In which R is the flexural strength of the specimen in MPa, P is the compressive force in N, L is the span length of the specimen, which is 390 mm, b is the width of the beam cross-section which is 100 mm and d is the height (depth) of the beam cross-section which is 100 mm.

The specimens were broken at 28 day and the Results were showed in [Table 5](#).



Figure 5. Flexural Strength Test on Samples

3. RESULTS AND DISCUSSION

3.1. Flexural Strength

Referring to [Figure 6](#), the analysis of the 28 day flexural strength test results on samples containing Ceramic clay and Baghmisheh region clay shows that with an increase in the amount of clay, the flexural strength of the samples has decreased compared to the CL0. The lowest flexural strength of Ceramic clay samples was related to CLA30 with value of 1.37 MPa, and the highest was related to CLA10 with value of 2.87 MPa. Furthermore, regarding samples of Baghmisheh region clay, the lowest flexural strength was related to CLB30 with value 1.11 MPa, and the highest was related to CLB10 with value 2.13 MPa. Compared to the CL0,

the samples containing 10, 20, and 30 percent Ceramic clay showed a reduction in strength of 49.98%, 62.94%, 76.09%, and samples containing 10, 20, and 30 percent Baghmisheh region clay showed a reduction in strength of 62.84%, 74.84%, and 80.60%. In general, increasing the amount of clay leads to an increase in the proportion of a weaker phase, changes in the microstructure, and disruption of the cement hydration process, also it can weaken the structural integrity and internal cohesion of the concrete, consequently reducing its resistance to flexural strength of the samples. [Table 5](#), shows the results of flexural strength.

Table 5. Flexural Strength Results

Sample Name	28 day (MPa)
CL0 (Control)	5.73
CLA10	2.87
CLA20	2.12
CLA30	1.37
CLB10	2.13
CLB20	1.44
CLB30	1.11

Comparing the strength of samples containing Ceramic clay and Baghmisheh region clay, it has been observed that the strength of samples with Ceramic clay was higher than the strength of samples with Baghmisheh region clay. Specifically, samples with 10, 20, and 30 percent Baghmisheh region clay, a reduction of 25.71%, 32.11%, and

18.88% was observed compared to Ceramic clay samples. In summary, the difference in the flexural strength results of concrete samples containing Ceramic clay and Baghmisheh region clay is likely due to differences in their chemical and mineral composition, physical properties, pozzolanic reactivity, and plasticity characteristics.

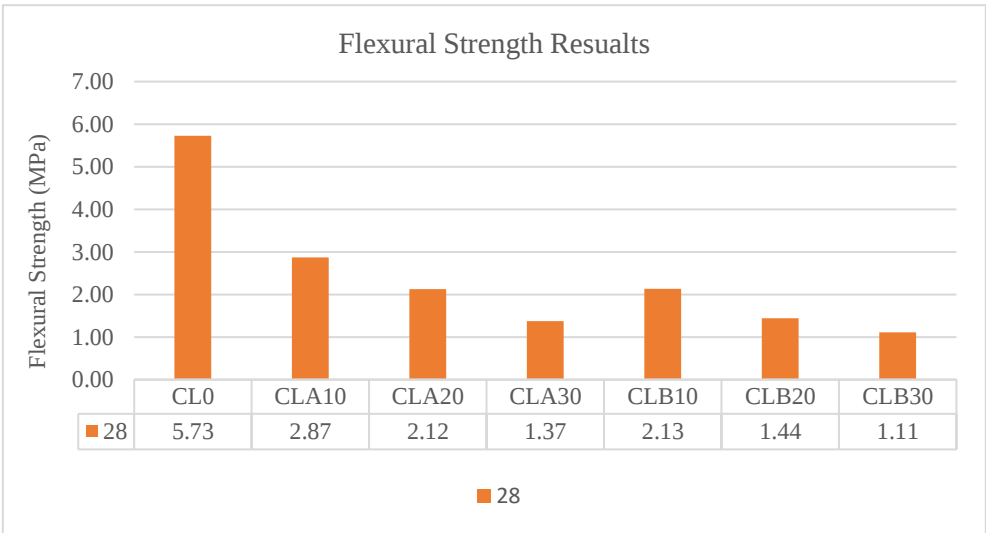


Figure 6. Result of Plastic Concrete Flexural Strength

3.2. Water Absorption Test

Referring to Figure 7, the analysis of the 28 day water absorption test results on samples containing Ceramic clay and Baghmisheh region clay shows that with an increase in the amount of clay, the water absorption of the samples has increased compared to the CL0. The lowest water absorption of Ceramic clay samples was related to CLA10 with a value of 0.93%, and the highest was related to CLA30 with a value of 5.32%. Furthermore, regarding samples of Baghmisheh region clay, the lowest water absorption was related to CLB10 with value of

3.39%, and the highest was related to CLB30 with value of 6.02%. Therefore, increasing the percentage of clay, especially clay with high hydrophilicity, and in the absence of proper mixing and curing management, can lead to a significant increase in water absorption in concrete samples by increasing porosity, specific surface area, and creating more porous structures. This can negatively affect the durability and other long-term properties of the concrete.

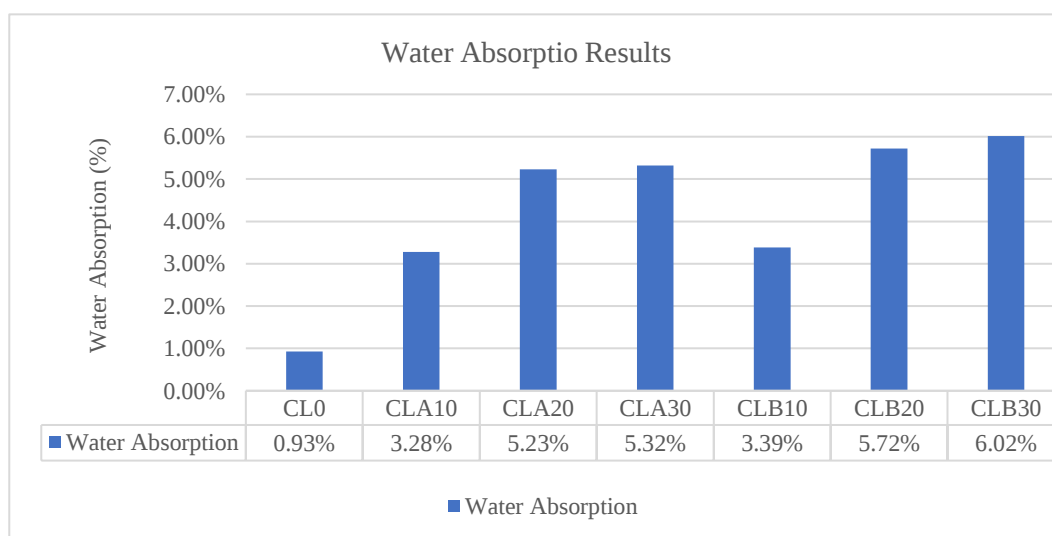
Table 6, shows the results of flexural strength.

Table 6. Water Absorption Results

Sample Name	Water Absorption
CL0 (Control)	0.93%
CLA10	3.28%
CLA20	5.23%
CLA30	5.32%
CLB10	3.39%
CLB20	5.72%
CLB30	6.02%

Comparing the water absorption of samples containing Ceramic clay and Baghmisheh region clay, it has been observed that the water absorption of samples with Ceramic clay was lower than the water absorption of samples with Baghmisheh region clay. Specifically, samples with 10, 20, and 30 percent Baghmisheh region clay showed increases of 3.30%, 9.40%, and 13.08%, respectively, compared to the ceramic clay samples.

In summary, the difference in the water absorption of concrete containing two different types of clay stems from variations in their mineral and chemical composition, physical properties (especially inherent water absorption capacity and specific surface area), and their impact on the microstructure of the concrete (particularly porosity and the interfacial transition zone).

**Figure 7.** Result of Plastic Concrete Water Absorption

3.3. Permeability Test

Referring to [Figure 8](#), the analysis of the 28 day permeability test results on samples containing Ceramic clay and Baghmisheh region clay shows that with an increase in the amount of clay, the permeability coefficient of the samples has increased compared to the CL0. The lowest permeability coefficient of Ceramic clay samples was related to CLA10 with a value of $1.10\text{E-}08$, and the highest was related to CLA30 with a value of $2.39\text{E-}08$. Furthermore, regarding samples of

Baghmisheh region clay, the lowest permeability coefficient was related to CLB10 with value of $1.71\text{E-}08$, and the highest was related to CLB30 with value of $2.65\text{E-}08$. Therefore, increasing the percentage of clay, especially clay with high hydrophilicity, and in the absence of proper mixing and curing management, can lead to a significant increase in permeability coefficient in concrete samples by increasing porosity, specific surface area, and creating more porous structures. This can

negatively affect the durability and other long-term properties of the concrete.

Table 7, shows the results of permeability coefficient.

Table 7. Permeability Coefficient Results

Sample Name	Permeability Coefficient
CL0 (Control)	9.10E-10
CLA10	1.10E-08
CLA20	1.46E-08
CLA30	2.39E-08
CLB10	1.71E-08
CLB20	2.16E-08
CLB30	2.65E-08

Comparing the permeability coefficient of samples containing Ceramic clay and Baghmisheh region clay, it has been observed that the permeability coefficient of samples with Ceramic clay was lower than the permeability coefficient of samples with Baghmisheh region clay. Specifically, samples with 10, 20, and 30 percent Baghmisheh region clay

showed increases of 56.45%, 47.93%, and 10.70%, respectively, compared to the ceramic clay samples. In summary, the difference in the permeability coefficient of concrete containing two different types of clay stems from variations in their mineral and chemical composition, physical properties, and their impact on the microstructure of the concrete.

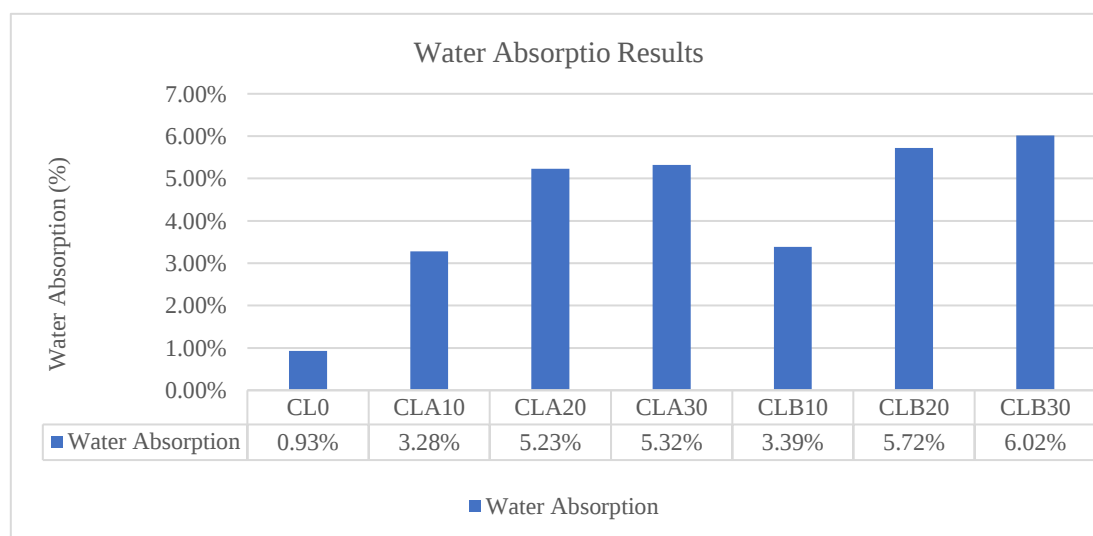


Figure 8. Result of Plastic Concrete Permeability Coefficient

4. CONCLUSION

The obtained results are summarized in [Table 8](#).

Table 8. Results of Plastic Concrete

Sample Name	Clay Type	W/C	Compressive Strength (MPa)		Flexural Strength (MPa)	Tensile Strength (MPa)		Permeability Coefficient	Water Absorption (%)
			7 day	28 day		7 day	28 day		
CL0 (Control)	-	0.45	18.75	27.97	5.73	1.89	2.40	9.10E-10	0.93%
CLA10	Ceramic clay	0.75	13.90	21.03	2.87	1.29	1.94	1.10E-08	3.28%
CLA20	Ceramic clay	0.75	13.90	9.93	2.12	0.46	0.86	1.46E-08	5.23%
CLA30	Ceramic clay	0.75	4.45	7.33	1.37	0.00	0.48	2.39E-08	5.32%
CLB10	Baghmisheh Region Clay	0.75	9.75	13.43	2.13	0.65	1.36	1.71E-08	3.39%
CLB20	Baghmisheh Region Clay	0.75	5.95	9.27	1.44	0.46	0.76	2.16E-08	5.72%
CLB30	Baghmisheh Region Clay	0.75	4.10	6.60	1.11	0.00	0.40	2.65E-08	6.02%

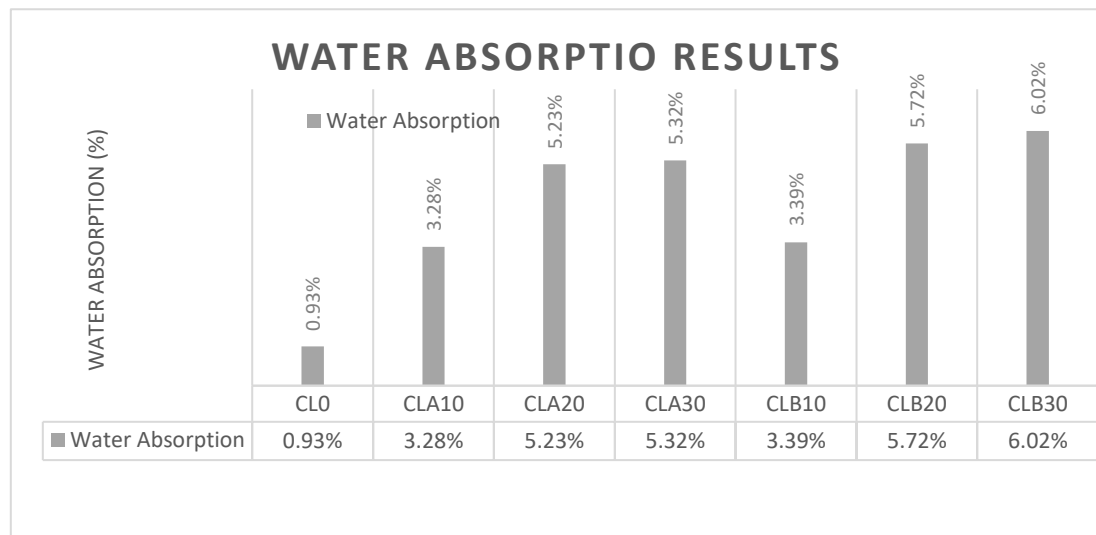


Figure 9. Result of Plastic Concrete Permeability Coefficient

The analysis of compressive strength, tensile strength, flexural strength, water absorption, and permeability tests on concrete samples containing varying percentages (0%, 10%, 20%, and 30%) of Ceramic clay and Baghmisheh region clay reveals the following:

1. Increasing the amount of either Ceramic clay or Baghmisheh region clay generally leads to a decrease in compressive strength at both 7 and 28 days compared to the CL0. Ceramic clay samples consistently exhibit higher compressive strength than Baghmisheh region clay samples at the same clay percentages.
2. Increasing the amount of either Ceramic clay or Baghmisheh region clay generally leads to a decrease in tensile strength at both 7 and 28 days compared to the CL0. Ceramic clay samples consistently exhibit higher tensile strength than

Baghmisheh region clay samples at the same clay percentages.

3. Similar to compressive and tensile strength, increasing the amount of either clay type generally results in a decrease in flexural strength compared to CL0. Ceramic clay samples demonstrate higher flexural strength than Baghmisheh region clay samples at comparable clay contents.

4. Increasing the percentage of either Ceramic clay or Baghmisheh region clay leads to an increase in water absorption compared to the control sample (CL0). Ceramic clay samples exhibit lower water absorption than Baghmisheh region clay samples at the same clay percentages.

5. Similar to water absorption, increasing the percentage of either Ceramic clay or Baghmisheh region clay leads to an increase in permeability

coefficient compared to the control sample (CL0). Ceramic clay samples exhibit lower permeability coefficient than Baghmisheh region clay samples at the same clay percentages.

The incorporation of both Ceramic clay and Baghmisheh region clay as partial replacements for cement generally reduces compressive, tensile and flexural strength while increasing water absorption and permeability coefficient of the concrete. However, Ceramic clay consistently outperforms Baghmisheh region clay across all tested properties, exhibiting higher strength and lower water absorption at comparable replacement levels. This difference is likely attributed to variations in their chemical and mineral composition, physical

properties (such as particle size and surface area), pozzolanic reactivity, and plasticity characteristics, ultimately influencing the microstructure and density of the resulting concrete. These findings also indicate that processing the same type of clay can significantly influence the resulting properties."

Despite these promising findings, some limitations should be acknowledged. First, this study primarily focused on short-term mechanical performance; long-term durability aspects, such as freeze-thaw resistance and chemical stability, require further investigation. Additionally, the study was limited to specific clay amount —future research could explore a wider range of parameters, including alternative types of clay and different types of clay

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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